

1 WHAT IS CLAIMED IS:

2 1. In a digital communication system, a method for communicating
3 comprising the steps of:
4 transmitting signals from one or more transmitter antenna elements;
5 receiving said signals from via a plurality of receiver antenna elements;
6 wherein separation of radiation patterns among either said transmitter antenna
7 elements or said receiver antenna elements is insufficient to establish completely
8 isolated spatial directions for communication; and wherein
9 at least one of said transmitting and receiving steps comprises processing said
10 signals to increase isolation between spatial directions employed for communication at a
11 common frequency.

12

13 2. The method of claim 1 wherein a channel coupling said plurality of
14 transmitter antenna elements and receiver antenna elements at said common frequency is
15 characterized by a spatial channel matrix having a rank greater than one.

16

17 3. In a digital communication system, a method for communicating
18 comprising the steps of:
19 transmitting signals from one or more transmitter antenna elements;
20 receiving said signals via a plurality of receiver antenna elements;
21 wherein separation of radiation patterns among either said transmitter antenna
22 elements or said receiver antenna elements is insufficient to establish completely
23 isolated spatial directions for communication; and wherein
24 at least one of said transmitting and receiving steps comprises processing said
25 signals to increase isolation between subchannels, each subchannel associated with a spatial
26 direction and a bin of a substantially orthogonalizing procedure.

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28 4. The method of claim 3 wherein said substantially orthogonalizing
29 procedure belongs to a group including: an inverse Fast Fourier Transform, a Fast Fourier
30 Transform, a Hilbert transform, a wavelet transform, and processing through a set of bandpass
31 filter/frequency upconverter pairs operating at spaced apart frequencies..

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33 5. In a digital communication system, a method for preparing a sequence of
34 symbols for transmission via a plurality of inputs of a channel:

35 a) inputting said symbols of said sequence into a plurality of inputs
36 corresponding to a plurality of subchannels of said channel, each subchannel corresponding to
37 an input bin of a transmitter substantially orthogonalizing procedure and a spatial direction;

38 b) for each input bin, spatially processing symbols inputted to said subchannels
39 corresponding to said input bin, to develop a spatially processed symbol to assign to each
40 combination of channel input and input bin of said transmitter substantially orthogonalizing
41 procedure; and

42 c) applying, independently for each said channel input, said transmitter
43 substantially orthogonalizing procedure to said spatially processed symbols assigned to each
44 said channel input.

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46 6. The method of claim 5 wherein said b) step has the effect of making
47 spatial directions of said subchannels into a set of orthogonal spatial dimensions.

48

49 7. The method of claim 5 wherein said transmitter substantially
50 orthogonalizing procedure belongs to one of a group consisting of an inverse Fast Fourier
51 Transform, a Fast Fourier Transform, a discrete cosine transform, a Hilbert transform, a
52 wavelet transform, and processing through a plurality of bandpass filter/frequency converter
53 pairs centered at spaced apart frequencies.

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55 8. The method of claim 5 further comprising the step of, after said c) step,
56 applying a cyclic prefix processing procedure to a result of said substantially orthogonalizing
57 procedure independently for each channel input.

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59 9. The method of claim 5 wherein said transmitter substantially
60 orthogonalizing procedure is optimized to reduce interference to unintended receivers.

61

62 10. The method of claim 5 wherein said b) step comprises, for each
63 particular input bin, multiplying a vector comprising symbols allocated to subchannels
64 corresponding to said input bin by a beneficial weighting matrix, elements of a result vector of
65 said multiplying step corresponding to different channel inputs of said plurality of channel
66 inputs.

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68 11. The method of claim 10 wherein said beneficial weighting matrix
69 comprises an input singular matrix of a matrix containing values representing characteristics of
70 said channel, said coupling said plurality of channel inputs to one or more channel outputs.

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72 12. The method of claim 10 wherein said beneficial weighting matrix is
73 obtained from a matrix containing values representing characteristics of a channel coupling
74 said plurality of channel inputs to one or more channel outputs.

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76 13. The method of claim 10 wherein said beneficial weighting matrix is
77 chosen to reduce interference to unintended receivers.

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79 14. The method of claim 13 wherein said beneficial weighting matrix is
80 chosen based upon characterization of a desired signal subspace.

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82 15. The method of claim 14 wherein said beneficial weighting matrix is
83 chosen further based upon characterization of an undesired signal subspace.

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85 16. The method of claim 15 wherein characterizations of said desired signal
86 subspace and said undesired signal subspace are averaged over at least one of time and
87 frequency.

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89 17. The method of claim 10 wherein said b) step comprises performing said
90 spatial processing step so as to reduce interference radiated to unintended receivers.

91

92 18. The method of claim 10 wherein said b) step comprises, for each input
bin, allocating symbols to each combination of channel input and input bin so that there

93 is a one-to-one mapping between spatial direction of a particular subchannel to which a
94 particular symbol has been allocated and channel input to which said particular symbol
95 is allocated.

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97 19. The method of claim 10 further comprising the step of prior to said b)
98 step applying a coding procedure to said symbols.

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100 20. The method of claim 19 wherein said coding procedure is applied
101 independently for each of said subchannels.

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103 21. The method of claim 19 wherein said coding procedure is applied
104 independently for each group of subchannels corresponding to an input bin of said substantially
105 orthogonalizing procedure.

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107 22. The method of claim 19 wherein said coding procedure is applied
108 independently for each group of subchannels corresponding to a particular spatial direction.

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110 23. The method of claim 19 wherein said coding procedure is applied
111 integrally across all of said subchannels.

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113 24. The method of claim 19 wherein said coding procedure belongs to a
114 group consisting of: convolutional coding, Reed-Solomon coding, CRC coding, block coding,
115 trellis coding, turbo coding, and interleaving.

116

117 25. The method of claim 19 wherein said coding procedure comprises a
118 trellis coding procedure.

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120 26. The method of claim 25 wherein a code design of said trellis coding
121 procedure is based on one of: improved bit error performance in interference channels, a
122 periodic product distance metric, exhaustive code polynomial search for favorable bit error
123 rate polynomial searches, combined weighting of product distance and Euclidean distance,

124 product distance of multiple Euclidean distances over short code segments or over a multi-
125 dimensional symbol, and sum of product distances over short code segments.

126

127 27. The method of claim 25 wherein a code design of said trellis coding
128 procedure is optimized for performance in a fading matrix channel.

129

130 28. The method of claim 19 wherein said coding procedure comprises a one-
131 dimensional trellis coding procedure followed by an interleaving procedure with sequential
132 groups of symbols output by said trellis coding having their internal order maintained by said
133 interleaving procedure.

134

135 29. The method of claim 19 wherein said coding procedure comprises a
136 multi-dimensional trellis coding procedure followed by an interleaving procedure with groups
137 of one-dimensional symbols output simultaneously by said multi-dimensional trellis coding
138 procedure having their internal order maintained by said interleaving procedure.

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140 30. The method of claim 10 wherein bit loading and power are allocated to
141 each subchannel.

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143 31. The method of claim 10 further comprising the step of retransmitting
144 symbols by repeating at least one of said a), b), and c) steps upon receipt of a notification that
145 said symbols to be retransmitted have been incorrectly received.

146

147 32. The method of claim 10 wherein said channel comprises a wireless
148 channel and said plurality of channel inputs are associated with a corresponding plurality of
149 transmitter antenna elements

150

151 33. The method of claim 32 wherein said plurality of transmitter antenna
152 elements are co-located.

153

154 34. The method of claim 32 wherein said plurality of transmitters are at
155 disparate locations.

156

157 35. A method of processing a sequence of symbols received via a plurality of
158 outputs of a channel, said method comprising the steps of:

159 a) applying a receiver substantially orthogonalizing procedure to said sequence
160 of symbols, said procedure being applied independently for each of said plurality of channel
161 outputs, each output symbol of said receiver substantially orthogonalizing procedure
162 corresponding to a particular output bin and a particular one of said channel outputs; and

163 b) for each output bin, spatially processing symbols corresponding to said
164 output bin to develop spatially processed symbols assigned to a plurality of spatial directions,
165 each combination of spatial direction and output bin specifying one of a plurality of
166 subchannels.

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168 36. The method of claim 35 wherein said b) step has the effect of making
169 said plurality of spatial directions into a set of orthogonal spatial dimensions.

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171 37. The method of claim 35 wherein said receiver substantially
172 orthogonalizing procedure belongs to one of a group consisting of an inverse Fast Fourier
173 Transform, a Fast Fourier Transform, a discrete cosine transform, a Hilbert transform, a
174 wavelet transform, and processing through a plurality of bandpass filter/frequency converter
175 pairs centered at spaced apart frequencies.

176

177 38. The method of claim 35 further comprising the step of, prior to said a)
178 step, applying a cyclic prefix removal procedure to said sequence of symbols independently
179 for each of said channel outputs.

180

181 39. The method of claim 35 wherein said receiver substantially
182 orthogonalizing procedure is optimized to reduce deleterious effects of interference from
183 undesired co-channel transmitters.

184

185 40. The method of claim 35 wherein said b) step comprises, for each
186 particular output bin, multiplying a vector comprising symbols of said output bin by a
187 beneficial weighting matrix, elements of a result vector of said multiplying step corresponding
188 to different spatial directions.

189

190 41. The method of claim 40 wherein said beneficial weighting matrix
191 comprises an output singular vector of a matrix containing values representing characteristics
192 of said channel, said channel coupling one or more channel inputs to said plurality of channel
193 outputs.

194

195 42. The method of claim 40 wherein said beneficial weighting matrix is
196 chosen to minimize deleterious effects of interference from undesired transmitters.

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198 43. The method of claim 42 wherein said beneficial weighting matrix is
199 chosen based upon characterization of a desired signal subspace.

200

201 44. The method of claim 43 wherein said beneficial weighting matrix is
202 chosen further based upon characterization of an undesired signal subspace.

203

204 45. The method of claim 44 wherein said characterizations of said desired
205 signal subspace and said undesired signal subspace are averaged over at least one of time and
206 frequency.

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208 46. The method of claim 40 wherein said beneficial weighting matrix is
209 obtained from a matrix containing values representing characteristics of said channel, said
210 channel coupling one or more channel inputs and said plurality of channel outputs.

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212 47. The method of claim 46 wherein said beneficial weighting matrix is
213 obtained by an MMSE procedure.

214

215 48. The method of claim 35 further comprising the step of after said b) step
216 applying a decoding procedure to said symbols.

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218 49. The method of claim 48 wherein said decoding procedure is applied
219 independently for each of said plurality of subchannels.

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221 50. The method of claim 48 wherein said decoding procedure is applied
222 independently for each group of subchannels corresponding to an output bin of said
223 substantially orthogonalizing procedure.

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225 51. The method of claim 48 wherein said decoding procedure is applied
226 independently for each group of subchannels corresponding to a spatial direction.

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228 52. The method of claim 48 wherein said decoding procedure is applied
229 integrally across all of said plurality of subchannels.

230

231 53. The method of claim 48 wherein said decoding procedure belongs to a
232 group consisting of: Reed-Solomon decoding, CRC decoding, block decoding, and de-
233 interleaving.

234

235 54. The method of claim 48 wherein said decoding procedure comprises a
236 code sequence detection procedure to decode a trellis code, or convolutional code.

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238 55. The method of claim 54 wherein said code sequence detection procedure
239 employs a metric belonging to a group consisting of: Euclidean metric, weighted Euclidean
240 metric, and Hamming metric.

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242 56. The method of claim 48 wherein said decoding procedure reduces
243 deleterious effects of interference from undesired transmitters.

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245 57. The method of claim 35 further comprising the step of:

246 sending a retransmission request when received symbols are
247 determined to include errors.

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249 58. The method of claim 35 wherein said channel comprises a wireless
250 channel and said plurality of channel outputs are coupled to a plurality of corresponding
251 receiver antenna elements.

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253 59. The method of claim 35 wherein said plurality of receiver antenna
254 elements are co-located.

256 60. The method of claim 35 wherein said plurality of receiver antenna
257 elements are at disparate locations.

259 61. In a digital communication system, a method for preparing a sequence of
260 symbols for transmission via a plurality of inputs to a channel, said method comprising the
261 steps of:

262 selecting a weighting vector for optimal transmission;
263 applying a transmitter substantially orthogonalizing procedure to
264 said sequence of symbols to develop a time domain symbol sequence; and
265 multiplying at least one symbol of said time domain symbol
266 sequence by said weighting vector to develop a result vector, elements of said result vector
267 corresponding to symbols to be transmitted via individual ones of said plurality of channel
268 inputs.

270 62. The method of claim 61 wherein said weighting vector comprises an
271 element indicating delay to be applied for a particular one of said plurality of channel inputs.

273 63. The method of claim 61 wherein said weighting vector is optimized to
274 reduce interference to unintended receivers.

276 64. The method of claim 61 wherein said weighting vector is chosen based
277 upon characterization of a desired signal subspace.

278

279 65. The method of claim 64 wherein said weighting vector is chosen further
280 based upon characterization of an undesired signal subspace.

281

282 66. The method of claim 65 wherein said characterizations of said desired
283 signal subspace and said undesired signal subspace are averaged over at least one of time and
284 frequency.

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286 67. The method of claim 61 wherein said channel comprises a wireless
287 channel and said plurality of channel inputs are associated with a plurality of transmitter
288 antenna elements.

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292 68. In a digital communication system, a method for processing a plurality
293 of symbols received via a plurality of outputs of a channel, said method comprising the steps
294 of:

295 selecting a weighting vector for optimal reception;
296 multiplying an input vector whose elements correspond to
297 symbols received substantially simultaneously via a selected one of said plurality of channel
298 outputs by said weighting vector to obtain a time domain symbol corresponding to a particular
299 input bin of a receiver substantially orthogonalizing procedure;

300 repeating said multiplying step for successive received symbols to
301 obtain time domain symbols corresponding to successive input bins of said receiver
302 substantially orthogonalizing procedure; and

303 applying said receiver substantially orthogonalizing procedure to
304 said obtained time domain symbols.

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306 69. The method of claim 68 wherein said weighting vector comprises an
307 element indicating delay to be applied for a particular one of said plurality of channel outputs.
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309 70. The method of claim 68 wherein said weighting vector is optimized to
310 reduce deleterious effects of interference from unintended transmitters.

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312 71. The method of claim 68 wherein said weighting vector is chosen based
313 upon characterization of a desired signal subspace.

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315 72. The method of claim 71 wherein said weighting vector is chosen further
316 based upon characterization of an undesired signal subspace.

317
318 73. The method of claim 72 wherein said characterizations of said desired
319 signal subspace and said undesired signal subspace are averaged over at least one of frequency
320 and time.

322 74. The method of claim 71 wherein said channel comprises a wireless
323 channel and said plurality of channel outputs are associated with a plurality of corresponding
324 receiver antenna elements.

325

326 75. In a digital communication system, a method of preparing symbols for
327 transmission via a plurality of inputs of a channel, said method comprising the steps of:

328 directing symbols to input bins of a transmitter substantially
329 orthogonalizing procedure so that each input bin has an allocated symbol;

330 for each particular input bin, spatially processing said symbol
331 allocated to said particular input bin to develop a spatially processed symbol vector, each
332 element of said spatially processed symbol vector being assigned to one of said channel
333 inputs;

334 applying said transmitter substantially orthogonalizing procedure
335 for a particular channel input, inputs to said substantially orthogonalizing procedure being for
336 each input bin, a symbol of said processed symbol vector for said input bin corresponding to
337 said particular channel input; and

338 repeating said applying step for each of said plurality of channel
339 inputs.

340

341 76. The method of claim 75 further comprising the step of:

342 applying a cyclic prefix processing procedure to outputs of said
343 substantially orthogonalizing procedure independently for each particular channel input.

344

345 77. The method of claim 75 wherein said transmitter substantially
346 orthogonalizing procedure is optimized to reduce interference to unintended receivers.

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348 78. The method of claim 75 wherein said processing step comprises:
349 multiplying said symbol allocated to said particular input bin by a
350 beneficial weighting vector to obtain said spatially processed symbol vector.

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352 79. The method of claim 78 wherein said beneficial weighting vector is an
353 input singular vector of a matrix storing values indicative of said channel, said channel
354 coupling said plurality of channel inputs and one or more channel outputs.

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356 80. The method of claim 78 wherein said beneficial weighting vector is
357 chosen to select a beneficial spatial direction for transmission.

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359 81. The method of claim 80 wherein said beneficial weighting vector is
360 chosen to reduce interference to unintended receivers.

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362 82. The method of claim 81 wherein said beneficial weighting vector is
363 chosen based upon characterization of a desired signal subspace

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365 83. The method of claim 82 wherein said beneficial weighting vector is
366 chosen further based upon characterization of an undesired signal subspace.

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368 84. The method of claim 83 wherein said characterizations of said desired
369 signal subspace and said undesired signal subspace are averaged over at least one of time and
370 frequency.

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372 85. The method of claim 75 wherein said channel comprises a wireless
373 channel and said plurality of channel inputs are associated with a corresponding plurality of
374 transmitter antenna elements.

375
376 86. In a digital communication system, a method for processing symbols
377 received by a plurality of outputs of a channel comprising the step of:
378 applying a receiver substantially orthogonalizing procedure to symbols received
379 via a particular one of said channel outputs;
380 repeating said applying step for each of said channel outputs to develop a result
381 vector for each of a plurality of output bins of said receiver substantially orthogonalizing
382 procedure, said result vector including a result symbol for each of said channel outputs; and

383 for each particular output bin of said receiver substantially orthogonalizing
384 procedure, spatially processing said result vector for said particular output bin to develop a
385 spatially processed result symbol for said particular output bin.

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387 87. The method of claim 86 further comprising the step of:
388 prior to said applying step, applying a cyclic prefix removal procedure to
389 symbols independently for each of said channel outputs.

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391 88. The method of claim 86 wherein said substantially orthogonalizing
392 procedure is optimized to reduce deleterious effects of interference from unintended
393 transmitters.

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395 89. The method of claim 86 wherein said spatially processing step comprises
396 multiplying a beneficial weighting vector by said result vector to obtain said spatially
397 processed result symbol.

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399 90. The method of claim 88 wherein said beneficial weighting vector is an
400 input singular vector of a matrix storing values indicative of characteristics of said channel,
401 said channel coupling one or more channel inputs and said plurality of channel outputs.

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403 91. The method of claim 88 wherein said beneficial weighting vector is
404 chosen to select a particular spatial direction for reception.

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406 92. The method of claim 91 wherein said beneficial weighting vector is
407 chosen to minimize deleterious effects of interference from unintended transmitters.

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409 93. The method of claim 91 wherein said beneficial weighting vector is
410 chosen based upon characterization of a desired signal subspace.

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412 94. The method of claim 93 wherein said beneficial weighting vector is
413 chosen based upon characterization of an undesired signal subspace.

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415 95. The method of claim 94 wherein said characterizations of said desired
416 signal subspace and said undesired signal subspace are averaged over at least one of time and
417 frequency.

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419 96. The method of claim 86 wherein said channel comprises a wireless
420 channel and said plurality of channel outputs are associated with a corresponding plurality of
421 channel outputs.

422
423 97. In a digital communication system including a communication channel
424 having one or more inputs and at least one or more outputs, a method for determining
425 characteristics of said channel based on signals received by said one or more outputs,
426 comprising the steps of:

427 a) receiving via said one or more channel outputs, at least ν training symbols
428 transmitted via a particular spatial direction of said channel, ν being an extent in symbol
429 periods of a duration of significant terms of an impulse response of a channel; and
430
431 b) applying a substantially orthogonalizing procedure to said received at least
432 ν training symbols to obtain a time domain response for said spatial direction; and
433
434 c) applying an inverse of said substantially orthogonalizing procedure to a zero-
435 padded version of said time domain response to obtain a frequency response for said particular
436 spatial direction.

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438 98. The method of claim 97 wherein said substantially orthogonalizing
439 procedure comprises an inverse Fast Fourier Transform and said inverse of said substantially
440 orthogonalizing procedure comprises a Fast Fourier Transform.

441
442 99. The method of claim 98 wherein said a) step comprises receiving exactly
443 ν training symbols.

444 100. The method of claim 97 further comprising the step of repeating said a),
445 b), c), and d) steps for a plurality of spatial directions.

445

446 101. The method of claim 99 wherein each of said plurality of spatial
447 directions corresponds to transmission through one of said plurality of channel inputs
448 exclusively.

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450 102. The method of claim 98 wherein said ν training symbols belong to a
451 burst of N symbols and said characteristics are determined for said burst.

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453 103. The method of claim 102 further comprising the steps of repeating said
454 a), b), c), and d) steps for successive bursts.

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456 104. The method of claim 103 further comprising the step of after, said b)
457 step, smoothing said time-domain response over successive bursts.

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459 105. The method of claim 104 wherein said smoothing step comprises Kalman
460 filtering.

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462 106. The method of claim 104 wherein said smoothing step comprises Wiener
463 filtering.

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465 107. The method of claim 97 wherein said communication channel comprises
466 known and unknown components, wherein said effects of said known components are removed
467 by deconvolution, and characteristics of said unknown components are determined by said a),
468 b), c), and d) steps, thereby reducing .

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470 108. In a digital communication system including a communication channel
471 having one or more inputs and one or more outputs, a method for determining characteristics
472 of said channel based on signals received via one or more channel outputs, comprising the
473 steps of:

474 receiving training symbols via said channel outputs; and

475 computing characteristics of said channel based on said received
476 training symbols and assumptions that an impulse response of said channel is substantially
477 time-limited and that variation of said impulse response over time is continuous.

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479 109. In a digital communication system, a method for communicating over a
480 channel having at least one input and at least one output, and having a plurality of either inputs
481 or outputs, said method comprising the steps of:

482 dividing said channel into a plurality of subchannels, each
483 subchannel corresponding to a combination of spatial direction and an input bin of a
484 substantially orthogonalizing procedure; and

485 communicating symbols over one or more of said plurality of
486 subchannels.

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488 110. In a digital communication system, a method for preparing a sequence of
489 symbols for transmission via a plurality of inputs of a channel, comprising the steps of:

490 a) inputting said symbols of said sequence into a plurality of
491 input corresponding to a plurality of subchannels of said channel, each subchannel
492 corresponding to an input bin of a transmitter substantially orthogonalizing procedure and a
493 channel input; and

494 b) applying, independently for each said channel input, said
495 transmitter substantially orthogonalizing procedure to said symbols assigned to each said
496 channel input.

497

498 111. A method of processing a sequence of symbols received via a plurality of
499 outputs of a channel, said method comprising the steps of:

500 a) applying a substantially orthogonalizing procedure to said
501 sequence of symbols, said procedure being applied independently for each of said plurality of
502 channel outputs, each output symbol of said substantially orthogonalizing procedure
503 corresponding to a subchannel identified by a combination of a particular output bin and a
504 particular one of said channel outputs; and

505 b) processing symbols in said subchannels.

506
507 112. In a digital communication system, apparatus for communicating
508 comprising:
509 a transmitter that transmits signals from one or more transmitter
510 antenna elements;
511 a receiver that receives said signals from via a plurality of
512 receiver antenna elements;
513 wherein separation of radiation patterns among either said
514 transmitter antenna elements or said receiver antenna elements is insufficient to
515 establish completely isolated spatial directions for communication; and wherein
516 at least one of said transmitter and said receiver comprises a
517 processor that processes said signals to increase isolation between spatial directions employed
518 for communication at a common frequency.

519
520 113. The apparatus of claim 112 wherein a channel coupling said plurality of
521 transmitter antenna elements and receiver antenna elements at said common frequency is
522 characterized by a spatial channel matrix having a rank greater than one.

523
524 114. In a digital communication system, apparatus for communicating
525 comprising:
526 a transmitter transmitting signals from one or more transmitter
527 antenna elements;
528 a receiver receiving said signals via a plurality of receiver
529 antenna elements;
530 wherein separation of radiation patterns among either said
531 transmitter antenna elements or said receiver antenna elements is insufficient to
532 establish completely isolated spatial directions for communication; and wherein
533 at least one of said transmitter and said receiver comprises a
534 processor that processes said signals to increase isolation between subchannels, each
535 subchannel associated with a spatial direction and a bin of a substantially orthogonalizing
536 procedure.

537

538 115. The apparatus of claim 1/14 wherein said substantially orthogonalizing
539 procedure belongs to a group including: an inverse Fast Fourier Transform, a Fast Fourier
540 Transform, a Hilbert transform, a wavelet transform, and processing through a set of bandpass
541 filter/frequency upconverter pairs operating at spaced apart frequencies..

542

543 116. In a digital communication system, apparatus for preparing a sequence of
544 symbols for transmission via a plurality of inputs of a channel:

545 a plurality of parallel subchannel inputs receiving said symbols, said parallel
546 subchannel inputs corresponding to a plurality of subchannels, each subchannel corresponding
547 to an input bin of a transmitter substantially orthogonalizing procedure and a spatial direction;

548 a spatial processor that, for each input bin, spatially processes symbols received
549 by said subchannel inputs corresponding to said input bin, to develop a spatially processed
550 symbol to assign to each combination of channel input and input bin of said transmitter
551 substantially orthogonalizing procedure; and

552 a substantially orthogonal procedure processor system that applies,
553 independently for each said channel input, said transmitter substantially orthogonalizing
554 procedure to said spatially processed symbols assigned to each said channel input.

555

556 117. The apparatus of claim 116 wherein said spatial processor has the effect
557 of making spatial directions of said subchannels into a set of orthogonal spatial dimensions.
558

559 118. The apparatus of claim 116 wherein said transmitter substantially
560 orthogonalizing procedure belongs to one of a group consisting of an inverse Fast Fourier
561 Transform, a Fast Fourier Transform, a discrete cosine transform, a Hilbert transform, a
562 wavelet transform, and processing through a plurality of bandpass filter/frequency converter
563 pairs centered at spaced apart frequencies.

564

565 119. The apparatus of claim 116 further comprising: a cyclic prefix processor
566 that applies a cyclic prefix processing procedure to a result of said substantially
567 orthogonalizing procedure independently for each channel input.

568

569 120. The apparatus of claim 116 wherein said transmitter substantially
570 orthogonalizing procedure is optimized to reduce interference to unintended receivers.

571

572 121. The apparatus of claim 116 wherein said spatial processor comprises, for
573 each particular input bin, a weight multiplier that multiplies a vector comprising symbols
574 allocated to subchannels corresponding to said input bin by a beneficial weighting matrix,
575 elements of a result vector of said weight multiplier corresponding to different channel inputs
576 of said plurality of channel inputs.

577

578 122. The apparatus of claim 121 wherein said beneficial weighting matrix
579 comprises an input singular matrix of a matrix containing values representing characteristics of
580 said channel, said channel coupling said plurality of channel inputs to one or more channel
581 outputs.

582

583 123. The apparatus of claim 121 wherein said beneficial weighting matrix is
584 obtained from a matrix containing values representing characteristics of a channel coupling
585 said plurality of channel inputs to one or more channel outputs.

586

587 124. The apparatus of claim 121 wherein said beneficial weighting matrix is
588 chosen to reduce interference to unintended receivers.

589

590 125. The apparatus of claim 124 wherein said beneficial weighting matrix is
591 chosen based upon characterization of a desired signal subspace.

592

593 126. The apparatus of claim 125 wherein said beneficial weighting matrix is
594 chosen further based upon characterization of an undesired signal subspace.

595

596 127. The apparatus of claim 126 wherein characterizations of said desired
597 signal subspace and said undesired signal subspace are averaged over at least one of time and
598 frequency.

599

600 128. The apparatus of claim 116 wherein said spatial processor operates so as
601 to reduce interference radiated to unintended receivers.

602

603 129. The apparatus of claim 116 wherein said spatial processor, allocates
604 symbols to each combination of channel input and input bin so that there is a one-to-one
605 mapping between spatial direction of a particular subchannel to which a particular symbol has
606 been allocated and channel input to which said particular symbol is allocated.

607

608 130. The apparatus of claim 116 further comprising a coder that applies a
609 coding procedure to said symbols prior to processing by said spatial processor.

610

611 131. The apparatus of claim 130 wherein said coding procedure is applied
612 independently for each of said subchannels.

613

614 132. The apparatus of claim 130 wherein said coding procedure is applied
615 independently for each group of subchannels corresponding to an input bin of said substantially
616 orthogonalizing procedure.

617

618 133. The apparatus of claim 130 wherein said coding procedure is applied
619 independently for each group of subchannels corresponding to a particular spatial direction.

620

621 134. The apparatus of claim 130 wherein said coding procedure is applied
622 integrally across all of said subchannels.

623

624 135. The apparatus of claim 130 wherein said coding procedure belongs to a
625 group consisting of: convolutional coding, Reed-Solomon coding, CRC coding, block coding,
626 trellis coding, turbo coding, and interleaving.

627

628 136. The apparatus of claim 130 wherein said coding procedure comprises a
629 trellis coding procedure.

630

631 137. The apparatus of claim 136 wherein a code design of said trellis coding
632 procedure is based on one of: improved bit error performance in interference channels, a
633 periodic product distance metric, exhaustive code polynomial search for favorable bit error
634 rate polynomial searches, combined weighting of product distance and Euclidean distance,
635 product distance of multiple Euclidean distances over short code segments or over a multi-
636 dimensional symbol, and sum of product distances over short code segments.

637

638 138. The apparatus of claim 136 wherein a code design of said trellis coding
639 procedure is optimized for performance in a fading matrix channel.

640

641 139. The apparatus of claim 130 wherein said coding procedure comprises a
642 one-dimensional trellis coding procedure followed by an interleaving procedure with sequential
643 groups of symbols output by said trellis coding having their internal order maintained by said
644 interleaving procedure.

645

646 140. The apparatus of claim 130 wherein said coding procedure comprises a
647 multi-dimensional trellis coding procedure followed by an interleaving procedure with groups
648 of one-dimensional symbols output simultaneously by said multi-dimensional trellis coding
649 procedure having their internal order maintained by said interleaving procedure.

650

651 141. The apparatus of claim 130 wherein bit loading and power are allocated
652 to each subchannel.

653

654 142. The apparatus of claim 116 further comprising an ARQ system that
655 retransmits symbols via at least one of said spatial processor, and said substantially
656 orthogonalizing procedure processor upon receipt of a notification that said symbols to be
657 retransmitted have been incorrectly received.

658

659 143. The apparatus of claim 116 wherein said channel comprises a wireless
660 channel and said plurality of channel inputs are associated with a corresponding plurality of
661 transmitter antenna elements

662

663 144. The apparatus of claim 142 wherein said plurality of transmitter antenna
664 elements are co-located.

665

666 145. The apparatus of claim 144 wherein said plurality of transmitters are at
667 disparate locations.

668

669 146. Apparatus of processing a sequence of symbols received via a plurality
670 of outputs of a channel, said apparatus comprising:

671 a substantially orthogonalizing procedure processor system that applies a
672 receiver substantially orthogonalizing procedure to said sequence of symbols, said procedure
673 being applied independently for each of said plurality of channel outputs, each output symbol
674 of said substantially orthogonalizing procedure corresponding to a particular output bin and a
675 particular one of said channel outputs; and

676 a spatial processor that, for each output bin, spatially processes symbols
677 corresponding to said output bin to develop spatially processed symbols assigned to a plurality
678 of spatial directions, each combination of spatial direction and output bin specifying one of a
679 plurality of subchannels.

680

681 147. The apparatus of claim 146 wherein said spatial processor operates to
682 make said plurality of spatial directions into a set of orthogonal spatial dimensions.

683

684 148. The apparatus of claim 146 wherein said receiver substantially
685 orthogonalizing procedure belongs to one of a group consisting of an inverse Fast Fourier
686 Transform, a Fast Fourier Transform, a discrete cosine transform, a Hilbert transform, a
687 wavelet transform, and processing through a plurality of bandpass filter/frequency converter
688 pairs centered at spaced apart frequencies.

689

690 149. The apparatus of claim 146 further comprising: a cyclic prefix processor
691 that applies a cyclic prefix removal procedure to said sequence of symbols independently for
692 each of said channel outputs.

693

694 150. The apparatus of claim 146 wherein said receiver substantially
695 orthogonalizing procedure is optimized to reduce deleterious effects of interference from
696 undesired co-channel transmitters.

697

698 151. The apparatus of claim 146 wherein said spatial processor comprises, for
699 each particular output bin, a weight multiplier that multiplies a vector comprising symbols of
700 said output bin by a beneficial weighting matrix, elements of a result vector of said multiplier
701 corresponding to different spatial directions.

702

703

704 152. The apparatus of claim 151 wherein said beneficial weighting matrix
705 comprises an output singular vector of a matrix containing values representing characteristics
706 of said channel, said channel coupling one or more channel inputs to said plurality of channel
outputs.

707

708 153. The apparatus of claim 151 wherein said beneficial weighting matrix is
709 chosen to minimize deleterious effects of interference from undesired transmitters.

710

711 154. The apparatus of claim 151 wherein said beneficial weighting matrix is
712 chosen based upon characterization of a desired signal subspace.

713

714 155. The apparatus of claim 154 wherein said beneficial weighting matrix is
715 chosen further based upon characterization of an undesired signal subspace.

716

717 156. The apparatus of claim 155 wherein said characterizations of said desired
718 signal subspace and said undesired signal subspace are averaged over at least one of time and
719 frequency.

720

721 157. The apparatus of claim 151 wherein said beneficial weighting matrix is
722 obtained from a matrix containing values representing characteristics of said channel, said
723 channel coupling one or more channel inputs and said plurality of channel outputs.

724

725 158. The apparatus of claim 157 wherein said beneficial weighting matrix is
726 obtained by an MMSE procedure.

727

728 159. The apparatus of claim 146 further comprising: a decoder that applies a
729 decoding procedure to said spatially processed symbols.

730

731 160. The apparatus of claim 159 wherein said decoding procedure is applied
732 independently for each of said plurality of subchannels.

733

734 161. The apparatus of claim 159 wherein said decoding procedure is applied
735 independently for each group of subchannels corresponding to an output bin of said
736 substantially orthogonalizing procedure.

737

738 162. The apparatus of claim 159 wherein said decoding procedure is applied
739 independently for each group of subchannels corresponding to a spatial direction.

740

741 163. The apparatus of claim 159 wherein said decoding procedure is applied
742 integrally across all of said plurality of subchannels.

743

744 164. The apparatus of claim 159 wherein said decoding procedure belongs to
745 a group consisting of: Reed-Solomon decoding, CRC decoding, block decoding, and de-
746 interleaving.

747

748 165. The apparatus of claim 159 wherein said decoding procedure comprises a
749 code sequence detection procedure to decode a trellis code, or convolutional code.

750

751 166. The apparatus of claim 165 wherein said code sequence detection
752 procedure employs a metric belonging to a group consisting of: Euclidean metric, weighted
753 Euclidean metric, and Hamming metric.

754

755 167. The apparatus of claim 159 wherein said decoding procedure reduces
756 deleterious effects of interference from undesired transmitters.

757

758 168. The apparatus of claim 146 further comprising:
759 a system that sends a retransmission request when received symbols are
760 determined to include errors.

761

762 169. The apparatus of claim 170 wherein said channel comprises a wireless
763 channel and said plurality of channel outputs are coupled to a plurality of corresponding
764 receiver antenna elements.

765

766 171. The apparatus of claim 170 wherein said plurality of receiver antenna
767 elements are co-located.

768

769 172. The apparatus of claim 170 wherein said plurality of receiver antenna
770 elements are at disparate locations.

771

772 173. In a digital communication system, apparatus for preparing a sequence of
773 symbols for transmission via a plurality of inputs to a channel, said apparatus comprising:
774 a substantially orthogonal procedure processor that applies a transmitter
775 substantially orthogonalizing procedure to said sequence of symbols to develop a time domain
776 symbol sequence; and

777 a weight multiplier that multiplies at least one symbol of said time domain
778 symbol sequence by a weighting vector selected for improved communication to develop a
779 result vector, elements of said result vector corresponding to symbols to be transmitted via
780 individual ones of said plurality of channel inputs.

781

782 174. The apparatus of claim 173 wherein said weighting vector comprises an
783 element indicating delay to be applied for a particular one of said plurality of channel inputs.
784

785 175. The apparatus of claim 174 wherein said weighting vector is optimized
786 to reduce interference to unintended receivers.
787

788 176. The apparatus of claim 173 wherein said weighting vector is chosen
789 based upon characterization of a desired signal subspace.
790

791 177. The apparatus of claim 176 wherein said weighting vector is chosen
792 further based upon characterization of an undesired signal subspace.
793

794 178. The apparatus of claim 177 wherein said characterizations of said desired
795 signal subspace and said undesired signal subspace are averaged over at least one of time and
796 frequency.
797

798 179. The apparatus of claim 173 wherein said channel comprises a wireless
799 channel and said plurality of channel inputs are associated with a
800 plurality of transmitter antenna elements.
801

802 180. In a digital communication system, apparatus for processing a plurality
803 of symbols received via a plurality of outputs of a channel, said apparatus comprising:
804 a weight multiplier that performs a multiplication of an input vector whose
805 elements correspond to symbols received substantially simultaneously via a selected one of said
806 plurality of channel outputs by a weighting vector to obtain a time domain symbol
807 corresponding to a particular input bin of a receiver substantially orthogonalizing procedure
808 and that repeats said multiplication for successive received symbols to obtain time domain
809 symbols corresponding to successive input bins of said receiver substantially orthogonalizing
810 procedure; and
811 a substantial orthogonalizing procedure processor that applies said substantially
812 orthogonalizing procedure processor to said obtained time domain symbols.

813

814 181. The apparatus of claim 180 wherein said weighting vector comprises an
815 element indicating delay to be applied for a particular one of said plurality of channel outputs.

816

817 182. The apparatus of claim 180 wherein said weighting vector is optimized
818 to reduce deleterious effects of interference from unintended transmitters.

819

820 183. The apparatus of claim 180 wherein said weighting vector is chosen
821 based upon characterization of a desired signal subspace.

822

823 184. The apparatus of claim 183 wherein said weighting vector is chosen
824 further based upon characterization of an undesired signal subspace.

825

826 185. The apparatus of claim 184 wherein said characterizations of said desired
827 signal subspace and said undesired signal subspace are averaged over at least one of frequency
828 and time.

829

830 186. The apparatus of claim 180 wherein said channel comprises a wireless
831 channel and said plurality of channel outputs are associated with a plurality of corresponding
832 receiver antenna elements.

833

834 187. In a digital communication system, apparatus for preparing symbols for
835 transmission via a plurality of inputs of a channel, said apparatus comprising:

836 a plurality of symbol inputs, each of said symbol inputs receiving a symbol
837 intended for a particular input bin of a transmitter substantially orthogonalizing procedure so
838 that each of a plurality of input bins of said transmitter substantially orthogonalizing
839 procedure has an allocated symbol;

840 a spatial processor that, for each particular input bin of said plurality of input
841 bins, spatially processes said symbol allocated to said particular input bin to develop a spatially
842 processed symbol vector, each element of said spatially processed symbol vector being
843 assigned to one of said channel inputs; and

844 a substantially orthogonalizing procedure processor that applies said
845 substantially orthogonalizing procedure for a particular channel input, inputs to said
846 substantially orthogonalizing procedure being for each input bin, a symbol of said processed
847 symbol vector for said input bin corresponding to said particular channel input, and that
848 applies said substantially orthogonalizing procedure for each of said plurality of channel inputs.
849

850 188. The apparatus of claim 187 further comprising:
851 a cyclic prefix processor that applies a cyclic prefix processing procedure to
852 outputs of said substantially orthogonalizing procedure independently for each particular
853 channel input.
854

855 189. The apparatus of claim 187 wherein said substantially orthogonalizing
856 procedure is optimized to reduce interference to unintended receivers.
857

858 190. The apparatus of claim 187 wherein said spatial processor comprises:
859 a weight multiplier that multiplies said symbol allocated to said particular input
860 bin by a beneficial weighting vector to obtain said spatially processed symbol vector.
861

862 191. The apparatus of claim 190 wherein said beneficial weighting vector is
863 an input singular vector of a matrix storing values indicative of characteristics of said channel,
864 said channel coupling said plurality of channel inputs and one or more channel outputs.
865

866 192. The apparatus of claim 190 wherein said beneficial weighting vector is
867 chosen to select a beneficial spatial direction for transmission.
868

869 193. The apparatus of claim 191 wherein said beneficial weighting vector is
870 chosen to reduce interference to unintended receivers.
871

872 194. The apparatus of claim 193 wherein said beneficial weighting vector is
873 chosen based upon characterization of a desired signal subspace
874

875 195. The apparatus of claim 194 wherein said beneficial weighting vector is
876 chosen further based upon characterization of an undesired signal subspace.
877

878 196. The apparatus of claim 195 wherein said characterizations of said desired
879 signal subspace and said undesired signal subspace are averaged over at least one of time and
880 frequency.

881

882 197. The apparatus of claim 187 wherein said channel comprises a wireless
883 channel and said plurality of channel inputs are associated with a corresponding plurality of
884 transmitter antenna elements.

885

886 198. In a digital communication system, apparatus for processing symbols
887 received by a plurality of outputs of a channel comprising:

888 a substantially orthogonalizing procedure processor that applies a receiver
889 substantially orthogonalizing procedure to symbols received via a particular one of said
890 channel outputs and that said applies said receiver substantially orthogonalizing procedure for
891 each of said channel outputs to develop a result vector for each of a plurality of output bins of
892 said substantially orthogonalizing procedure, said result vector including a result symbol for
893 each of said channel outputs; and

894 a spatial processor that, for each particular output bin of said substantially
895 orthogonalizing procedure, spatially processes said result vector for said particular output bin
896 to develop a spatially processed result symbol for said particular output bin.

897

898 199. The apparatus of claim 198 further comprising: a cyclic prefix removal
899 processor that applies a cyclic prefix removal procedure to symbols independently for each of
900 said channel outputs.

901

902 200. The apparatus of claim 198 wherein said substantially orthogonalizing
903 procedure is optimized to reduce deleterious effects of interference from unintended
904 transmitters.

905

906 201. The apparatus of claim 198 wherein said spatially processor comprises a
907 weight multiplier that multiplies a beneficial weighting vector by said result vector to obtain
908 said spatially processed result symbol.

909

910 202. The apparatus of claim 201 wherein said beneficial weighting vector is
911 an input singular vector of a matrix storing values indicative of characteristics of said channel,
912 said channel coupling one or more channel inputs and said plurality of channel outputs.

913

914 203. The apparatus of claim 201 wherein said beneficial weighting vector is
915 chosen to select a particular spatial direction for reception.

916

917 204. The apparatus of claim 203 wherein said beneficial weighting vector is
918 chosen to minimize deleterious effects of interference from unintended transmitters.

919

920 205. The apparatus of claim 204 wherein said beneficial weighting vector is
921 chosen based upon characterization of a desired signal subspace.

922

923 206. The apparatus of claim 205 wherein said beneficial weighting vector is
924 chosen based upon characterization of an undesired signal subspace.

925

926 207. The apparatus of claim 206 wherein said characterizations of said desired
927 signal subspace and said undesired signal subspace are averaged over at least one of time and
928 frequency.

929

930 208. The apparatus of claim 198 wherein said channel comprises a wireless
931 channel and said plurality of channel outputs are associated with a corresponding plurality of
932 channel outputs.

933

934 209. In a digital communication system including a communication channel
935 having one or more inputs and at least one or more outputs apparatus for determining

936 characteristics of said channel based on signals received by said one or more outputs,
937 comprising:
938 a receiver system receiving via said one or more channel outputs, at least
939 training symbols transmitted via a particular spatial direction of said channel, being an extent
940 in symbol periods of a duration of significant terms of an impulse response of a channel;
941 a substantially orthogonalizing procedure processor that applies a substantially
942 orthogonalizing procedure processor to said received at least training symbols to obtain a
943 time domain response for said particular spatial direction; and
944 an inverse substantially orthogonalizing procedure processor that applies an
945 inverse of said substantially orthogonalizing procedure to a zero-padded version of said time
946 domain response to obtain a frequency response for said particular spatial direction.
947

948 210. The apparatus of claim 209 wherein said substantially orthogonalizing
949 procedure comprises an inverse Fast Fourier Transform and said inverse of said substantially
950 orthogonalizing procedure comprises a Fast Fourier Transform.

951

952 211. The apparatus of claim 209 wherein said receiver system receives exactly
953 training symbols.

954

955 212. The apparatus of claim 209 wherein said receiver system, said
956 substantially orthogonalizing procedure processor and said inverse substantially
957 orthogonalizing procedure process operate repeatedly for a plurality of spatial directions.

958

959 213. The apparatus of claim 209 wherein each of said plurality of spatial
960 directions corresponds to transmission through one of said plurality of channel inputs
961 exclusively.

962

963 214. The apparatus of claim 209 wherein said training symbols belong to a
964 burst of N symbols and said characteristics are determined for said burst.

965

966 215. The apparatus of claim 214 said receiver system, said substantially
967 orthogonalizing procedure processor and said inverse substantially orthogonalizing procedure
968 process operate repeatedly for a plurality of bursts.

969

970 216. The apparatus of claim 215 further comprising:
971 means for smoothing said time-domain response over successive bursts.

972

973 217. The apparatus of claim 216 wherein said smoothing means comprises:
974 means for Kalman filtering said time-domain response over successive bursts.

975

976 218. The apparatus of claim 217 wherein said smoothing means comprises
977 means for Wiener filtering said time-domain response over successive bursts.

978

979 219. The apparatus of claim 209 wherein said communication channel
980 comprises known and unknown components, wherein said effects of said known components
981 are removed by deconvolution, and characteristics of said unknown components are
982 determined by said a), b), c), and d) steps, thereby reducing .

983

984 220. In a digital communication system including a communication channel
985 having one or more inputs and one or more outputs, apparatus for determining characteristics
986 of said channel based on signals received via one or more channel outputs, comprising:
987 a receiver that receives training symbols via said channel outputs; and
988 a processor that computes characteristics of said channel based on said received
989 training symbols and assumptions that an impulse response of said channel is substantially
990 time-limited and that variation of said impulse response over time is continuous.

991

992 221. In a digital communication system, apparatus for communicating over a
993 channel having at least one input and at least one output, and having a plurality of either inputs
994 or outputs, said apparatus comprising:

995 means for dividing said channel into a plurality of subchannels, each subchannel
996 corresponding to a combination of spatial direction and an input bin of a substantially
997 orthogonalizing procedure; and
998 means for communicating symbols over one or more of said plurality of
999 subchannels.

1000

1001 222. In a digital communication system, apparatus for preparing a sequence of
1002 symbols for transmission via a plurality of inputs of a channel, said apparatus comprising:
1003 a plurality of parallel subchannel inputs that receive said sequence of symbols,
1004 said subchannel inputs corresponding to a plurality of subchannels, each subchannel
1005 corresponding to an input bin of a transmitter substantially orthogonalizing procedure and a
1006 channel input; and
1007 a substantially orthogonalizing procedure processor that applies, independently
1008 for each said channel input, said transmitter substantially orthogonalizing procedure to said
1009 symbols assigned to each said channel input.

1010

1011 223. Apparatus for processing a sequence of symbols received via a plurality
1012 of outputs of a channel, said apparatus comprising the steps of:
1013 a substantially orthogonalizing procedure processor that applies a receiver
1014 substantially orthogonalizing procedure to said sequence of symbols, said procedure being
1015 applied independently for each of said plurality of channel outputs, each output symbol of said
1016 receiver substantially orthogonalizing procedure corresponding to a subchannel identified by a
1017 combination of a particular output bin and a particular one of said channel outputs; and
1018 a processor that processes symbols in said subchannels

Add A